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6 INTELLECTUAL PERFORMANCE UNDER STRESS

10 Robert G. Pachella

Project Director

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I. OBJECTIVES OF CONTRACT PROGRAM

This is an annual report for the nominal period 1 July 1974 through 30 June 1975 on Contract No. F44620-72-C-0019. Because of changes of principle investigator, contract duration and reporting dates, this report will also effectively cover work completed during the period 31 March 1974 to 30 June 1974. Since 1971 the Human Performance Center has been conducting a program of research on intellectual performance under stress. The original contract period, 1 October 1971 through 30 September 1973, was continued through 30 September 1975. Recently, the contract was further extended, without additional funding through 30 June 1976.

Since October 1, 1974 continued progress has been made in the study of component mental activities that play an important role in reliable, efficient performance of military operational duties. These activities are being studied in isolation and under stressful conditions. We are focusing our investigations on stress resulting from excessive task demands such as tasks requiring information overload, unrealistic requirements for speed or precision and the need to conduct two or more relatively independent activities concurrently. Our goal is to identify the differential susceptibility of the component skills to the effects of stress, to suggest training procedures for producing resistance to such stress effects and to define principles of man-machine system design that will minimize the incidence of stress-produced decrements in performance.

During the past year work has progressed on identifying the effects of these kinds of stressors on selective remembering, on speeded retrieval of information and decision and on interference with the performance of human motor activities. We have also developed a battery of information processing tasks suitable for examining the profile of performance decrement associated with a particular stressor.

Work is continuing on the following objectives, as it has throughout the contract period:

1. Conduct research to assess the effect of speed stress, memory overload, and other task-induced stressors on performance of a range of human information processing tasks.
2. Formulate principles of human reactions to stress that have implications for equipment or job design, for development of training programs or training aids or for the selection and assignment of military personnel.
3. Conduct research on the relationship between the performance of elemental information processing activities and the performance of integrated skilled activities of the kind required in a military setting.

II. PUBLICATIONS

During the period of this report 15 articles based on current work have appeared in scientific journals or in the Human Performance Center Technical Report series. These are listed below along with their respective report numbers based on the local account number for contract F44620-72-C-0019.

Two articles have been accepted for publication and seven articles are currently undergoing editorial consideration. These are listed as indicated.

Published Reports

Bjork, R. A. Theoretical implications of directed forgetting. Chapter in Coding Processes in Human Memory. A. W. Melton & E. Martin (Eds.), Washington, D. C., 1972. 010588-17-B

Martin, E. Stimulus encoding in learning and transfer. Chapter in Coding Processes in Human Memory. A. W. Melton & E. Martin (Eds.), Washington, D. C. 1972. 010588-18-B

Polzella, D. J. The effect of sleep-deprivation on short-term recognition memory. Human Performance Center Technical Report No. 47, April, 1974. 010588-19-T

Pew, R. W. Human perceptual-motor performance. Chapter in Human Information Processing: Tutorials in Performance and Cognition. B. H. Kantowitz (Ed.), Lawrence Erlbaum Associates, Washington, D. C., 1974. 010588-20-B

Wickens, C. D. The effects of time sharing on the performance of information processing tasks: A feedback control analysis. Human Performance Center Technical Report No. 51, August, 1974. 010588-21-T

Kieras, D. Analysis of the effects of word properties and limited reading time in a sentence comprehension and verification task. Human Performance Center Technical Report No. 53, August, 1974. 010588-22-T

Thomas, E. A. C The selectivity of preparation. Psychological Review, 19/4, 81, 442-464. 010588-23-J

Mayer, R. E. Acquisition processes and resilience under varying testing conditions for structurally different problem-solving procedures. Journal of Educational Psychology, 1974, 66, 644-656. 010588-24-J

Stokes, D. M. Anxiety level and tolerance in cognitive inconsistency. Chapter V of Pacification theory: A mathematical theory of cognitive consistency. Doctoral dissertation, University of Michigan, 1974. 010588-25-T

Pew, R. W. Levels of analysis in motor control. Brain Research, 1974, 71, 393-400. 010588-26-J

Elmes, D. G., & Bjork, R. A. The interaction of encoding and rehearsal processes in the recall of repeated and nonrepeated items. Journal of Verbal Learning and Verbal Behavior, 1975, 14, 30-42. 010588-27-J

Bjork, R. A. Short-term storage: The ordered output of a central processor. Chapter in Theoretical Developments in Cognitive Psychology, Vol. I. F. Restle (Ed.), Lawrence Erlbaum Associates, Hillsdale, N. J., 1975. 010588-28-B

Martin, E. Generation-recognition theory and the encoding specificity principle. Psychological Review, 1975, 82, 150-153. 010588-29-J

Mayer, R. E., & Greeno, J. G. Effects of meaningfulness and organization on problem solving and computability judgments. Memory and Cognition, 1975, 3, 356-362. 010588-30-J

Mayer, R. E., Stiehl, C. C., & Greeno, J. G. Acquisition of understanding and skill in relation to subjects' preparation and meaningfulness of instruction. Journal of Educational Psychology, 1975, 67, 331-350. 010588-31-J

Reports in Press

Bjork, R. A. Retrieval as a memory modifier: An interpretation of negative recency and related phenomena. In R. Solso (Ed.), Theories in Cognitive Psychology: The Loyola Symposium. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1975, in press.

Pachella, R. G., & Miller, J. O. Stimulus probability and same-different classification. Perception and Psychophysics, in press.

Reports Submitted for Publication

King, D. R. W., & Anderson, J. R. Long-term memory search: An intersecting trace activation model. Submitted to Journal of Verbal Learning and Verbal Behavior.

Miller, J. O., & Pachella, R. G. Encoding processes in memory scanning tasks. Submitted to Memory and Cognition.

Stanovich, K. E., & Pachella, R. G. The effect of stimulus probability and stimulus quality on reaction time tasks with 1 to 1 S-R mappings. Submitted to Memory and Cognition.

Bjork, R. A., & McClure, P. Encoding to update one'e memory. Submitted to Cognitive Psychology.

Bjork, R. A., & Jongeward, R. H. Rehearsal and mere rehearsal. Submitted to Psychological Review.

Mayer, R. E., Bjork, R. A., Pew, R. W., & Weintraub, D. J. Problem-solving under stress and anxiety. Submitted to Memory and Cognition.

Reitman, J. S. Skilled perception in Go: Deducing memory structure from response times. Submitted to Cognitive Psychology.

III. MAJOR ACCOMPLISHMENTS

The role of cognitive structure in the elimination of information overload (J. Reitman). Experts at complex games, such as Chess and Go, show an amazing ability to quickly extract and remember detail about specific game situations (i.e., the positions of all the pieces on the board at a particular point in time). Thus, what amounts to an example of extreme information overload for the novice, is not for the master. In our laboratories we have been able to confirm and extend the findings of others (e.g., Chase & Simon, 1973), that this superiority of the experts is not due to greater memorial capacity nor due to increased familiarity of game boards and pieces, since when shown situations where the placement of the pieces is a result of a random process, the experts do no better than the novices. Increasingly, our studies have moved us to the conclusion that the expert relies on the direct perception of complex structure in the visual display. That is, he may react as much to the visual appearance of the pattern on the board as he does to cognitive inferences about the nature of the game. We already know that the perceptual system is highly sensitive to high order, interactive relations in sensory data. What the expert appears to do is to transfer part of the control of complex decision processes to the more efficient mode of perceptual analysis.

This, of course, would have major implications for our concepts about the mode of display of the information necessary for the solution of a complex problem. Often the various aspects of a problem are presented separately in the form of abstract numerical data, tables and charts. If expert problem solvers in fact "perceptualize" information, then this would suggest the presentation of integrated displays where each variable of a problem would be mapped into a concrete dimension of a single spatial or temporal array. Thus, the problem solver could develop the ability across problems to utilize the perceptual system in order to extract the correlational structure needed to arrive at a solution.

It appears that the expert's perceptual processes recode the mass of presented information into well-defined, familiar clusters of elements, so that the units processed and remembered in a memory of fixed capacity consist of clusters rather than individual elements. Work in progress (Reitman, submitted) focuses on two aspects of this phenomenon. First, a technique is being developed to specify which elements belong in the perceived clusters and how the clusters join to form even higher level groups. Second, a complex cognitive system is being designed to model the way structured patterns are acquired, demonstrating the vast differences in performance between the expert and the non-expert human observers.

The technique delineates the observer's perceived structure from regularities in the order of elements he recalls and the time that elapses between the recall of successive elements. From these data, the technique indicates clusters and higher order groups based on the notion that 1) those elements that are recalled systematically near each other, though varying in actual order, are part of the same cluster, and 2) the time between two successively recalled elements of a cluster are short, that between elements recalled successively from two groups (the last of one and the first of the next) are long.

To verify that the structure designated by the technique is that actually perceived by the observer, experiments for collection of appropriate data were recently designed, and implementation of the computer-based facilities for the execution of these experiments (a scope and two light pens connected to a PDP-9) is nearly complete. Initially, subjects are to be asked to recall a set of well-learned patterns many times, many ways. The technique is then to be used to unfold structures; the inferred structures are then verified through further subject performance in a task involving recognition of parts of the patterns.

The model of the observer's acquisition of these patterns is being designed in collaboration with John Holland of the Logic of Computers Group here at Michigan. He has constructed an algorithm that theoretically allows the contents of memory to adapt in a way optimally suited to regularities in the environment. The model of the human observer's perceptual adaptation incorporates this algorithm in a system that matches the current input to similar patterns previously encountered, and constructs a detailed response to appropriate the system's goals and the features of the input. To date, a simple but complete version of this model is specified and is expected to be programmed, ready for proof and verification, by the end of summer. Plans have recently been made to expand the system to account for more complex aspects of human cognition as language acquisition and problem solving.

Manipulation of control processes in memory (R. Bjork). When an individual is faced with more information than he can possibly remember, learning strategies can be utilized that can optimize either short-term or long-term retention. We (Bjork, 1972, 1975) have been able to show in a series of studies that primary rehearsal, or the rote repetition of presented material, is efficient in maintaining information in short-term or working memory. Such rote rehearsal, however, has very little consequence for the long term retention of material. On the other hand, secondary rehearsal, or the elaboration and interassociation of presented material with previously learned information from long-term memory, is inefficient as a maintenance operation, but is essential for the transfer of information to long-term memory. Thus, it is an inefficient strategy for short-term recall, but maximizes long-term retention. Furthermore, the utilization of tests during the learning phase, seems to follow a similar pattern. We have been able to show (Bjork, in press) that tests given during training that require involvement of long-term memory and some depth of processing, can facilitate later efforts for retrieval. However, testing that involves simple, shallow retrieval from short-term memory during the learning phase will have little effect on long-term retention.

Retrieval of factual information under speed stress (J. Greeno). When factual information is stored in memory, a network of connections among concepts is established. Retrieval of a specific fact may take more or less time, depending on the way in which components of the fact are related in memory and on the process used to retrieve the information. We have studied effects of various structural features of information on the time taken to retrieve facts, and on the frequency of errors made when responses must be made quickly. Knowledge of the relationships between structure and retrieval time permits prediction of the kinds of questions on which people are likely to fail when they have little time for retrieval. A potential use of this knowledge is in guiding the organization of information (for example, in instructions or briefings) that will optimize the ease of retrieving facts of particular importance or facts that are likely to have to be retrieved in limited time or under other stressful conditions.

We have confirmed previous findings (e.g., Collins & Quillian, 1969) that information about categories is typically arranged in hierarchies, with more general properties stored at greater distance from specific instances than properties of the specific instances themselves. If a true statement contains ideas that are separated in the memory structure, more time is needed to retrieve the information. If a false statement contains ideas that are stored close to each other, then extra time will be taken before disconfirming information is retrieved. Additional aspects of this problem studied at HPC include John Anderson's finding that additional time during retrieval occurs when there is an idea in a statement that is included in many facts stored in memory. And in work supported by ARPA, we have found that a false statement takes longer to disconfirm if its two components come from propositions that share a common third idea than if its components come from unrelated propositions.

One effect of speed stress on retrieval of confirming evidence is relatively simple and supports what would be expected intuitively: Errors increase most on items requiring retrieval of most information--that is, more errors occur when the subject must make an inference than when needed information is stored directly. However, the results regarding negative decisions are not as easily derived from intuition. The errors that occur most often under speed stress are mistaken positive responses to false statements involving ideas that are indirectly linked in memory. Speed stress also causes a general increase in errors for both true and false items containing ideas that are related to many other things in memory. The major conclusion is that retrieval of factual information involves a kind of activation spreading through the network of ideas stored in memory, followed by a more analytic checking of the way in which ideas are related. Ideas that are closely enough related to produce a connection in the memory structure are likely to generate false positives when fast performance is required, and a general degradation of performance will occur when many facts are known about elements included in the situation.

In a further experiment, conducted by David King, it has been shown that this effect of connectedness holds for information in the form of equations whose terms are meaningful concepts, such as power = work/time, but not for nonsense information--for example, K = W/D. This suggests that the basic strategies of retrieving information are different in the two cases. When information stored in memory consists of relationships among concepts that are well understood, retrieval of factual information apparently involves a kind of activation spreading through the mental network of ideas, followed by a more analytic checking of the way in which ideas are related. Retrieval of information that is not meaningful to the operator seems to be a more systematic checking procedure, less susceptible to generation of false positives due to the presence of irrelevant connections among component elements.

Validation of a test battery of human performance (D. Weintraub). We have developed and are validating a battery of tests for the assessment of performance capabilities. The individual tests are portable surrogates for more elaborate experimental tasks that have been studied extensively in our laboratories for several years. The original validation experiment of the battern (Rose, 1974) showed the tests to be reliable and, for the most part, statistically independent.

Unlike the approach used in the development of other performance batteries, the strategy employed in our project was to select for testing experimental paradigms that had firm theoretical bases. In particular, the tests were selected in order to differentially weigh the various component mental activities presumed to underlie performance. The original study presented not only a large-scale (100 S's) validation of these notions, but also a standard body of normative data (means, standard deviations, intercorrelations) against which future data could be compared.

We have most recently been engaged in additional, practical validation studies. That there is need for a performance battery of the type we are attempting to develop is clear from the number of inquiries we have received in regard to this phase of our program. To date we have completed the data collection and analysis of one of these studies, are in the midst of setting up two others and have established contact with yet a fourth group. The completed study (in collaboration with Dr. George Brewer, University of Michigan

Medical School) involves the study of the ability of a particular drug to overcome the effects of high altitutde anoxia. Appropriate experimental and control groups were administered the test battery both in Ann Arbor and at the top of Pike's Peak. The preliminary results of the study indicate differential effects on various pattern tests as a result of transportation from Ann Arbor to Pike's Peak, but no effect of the administered drug.

Attention demands and motor performance (R. Pew). The study of the control and organization of motor skills and the allocation of attention and processing capacity within the motor system has been enhanced in recent years by the application of feedback control theory. As part of the current project we have reviewed and summarized this theoretical development (Pew, 1974a) and initiated experimentation dictated by its perspective (Pew, 1974b). Our experiments have shown that the automated nature acquired by motor skills as a result of extensive practice, does not necessarily reduce attentional demands during their performance. Rather, the automazation of particular motor patterns allows attention to be redirected to the establishment of higher levels of organization. The result is that extensive practice leads to the learning of something more general than the features of a specific movement pattern. General schemata for the generation of the movement patterns are formed so that scale factors and parameters of the original pattern can be efficiently adjusted in order to match potential distortions of the original movement that may be required in the completion of the task. As a result of this reallocation of attention (as opposed to a reduction of attentional demands), secondary tasks performed simultaneously with highly practiced movements do not necessarily show an advantage relative to those performed with less automated skills.

We have replicated previous findings that performance on a repeated segment of a continuous tracking task improves more rapidly than random control segments. There is also a consistent position effect within a trial block: Performance is consistently better for the first third of a trial than for the second third, which in turn is better than the final third. This is true for both repeated and random segments. We have also been able to show that the performance benefit resulting from the repeated segment transfers to the opposite arm from the one used in training. Under timesharing stress (additional attention demands) the repeated segment did not appear to be more resistent to performance deterioration than the random segments.

The application of control theory to the study of workload in multiple task performance has further allowed us to study the interaction among perception, perceptual-motor coordination, and motor output control (Wickens, 1974). These results suggest that workload is most heavily determined by the motor requirements of a task. If care is taken to minimize interference within modalities, little perceptual interference is observed.

<u>Learning structured material and subsequent performance under speed stress</u> (W. Whitten). It has been demonstrated that learning to recall a group of minimally related items may be the functional equivalent of organizing those items, thereby imposing a structure on them that is useful as a retrieval plan (Bower, 1970). Providing a structure during learning can in some situations at least, speed learning. The direct implication of these findings is that structure should be provided for optimal (i.e., fastest) learning. Two

fundamental questions pertinent to this conclusion remain unanswered, however. (1) Does information learned via provided-structure resist long-term forgetting as well as information that was learned without the structure? (2) Is the provided-structure information more or less resistant to stresses such as those induced by speeded recall situations? These two questions may not be independent in that the effects of speeded recall after a relatively short retention interval may parallel the effects of leisure recall after a lengthy delay. Both manipulations, in other words, may identify the weaknesses in either or both of the two learning situations.

A priori, it is not possible to predict which learning situation will provide more resistance to the pressure of speeded recall or to the effects of long retention intervals. Arguments can be posed for the superiority of either situation. On the one hand, since provided structure speeds initial learning, we could argue that this structure must be 'natural' for the S, thus should be easy to use under stressful conditions and should be resistant to forgetting over time. On the other hand, it may be argued that the S who learns a set of information in the absence of provided structure may develop an idiosyncratic organization that is more resistant to speed stress and time than information learned via provided structure. The longer time taken by the "free-learning" S may be reflected by an internal organization which "fits" his pre-experimental knowledge structure better than does the organization provided for the "provided-structure S". The experiment designed to answer these and associated questions is now almost complete.

Four conditions are included in this experiment: 1) hierarchy organization; 2) organized sets of items without an integrating structure; 3) random sets of items without an integrating structure; and 4) list. These four conditions were designed to provide maximal to minimal a priori organization, respectively. The nature of this experiment dictates a between-subjects design and twenty subjects are being tested in each condition. At present about 85% of the subjects have been tested.

The major problem of this type of research is the devising of ways to properly compare data from the different conditions. It is clear that simple measures of "trials-to-criterion" and "percent correct" are inadequate since these measures do not examine the particular effects of organizational structures on learning or on recall. For example, a subject in the list condition may take more trials than a subject in the hierarchy condition to learn the complete set of items. Examination of learning data from list-condition subjects shows, however, that these subjects generally have difficulty in adding just one or two last items to their recall protocols. The majority of items in their protocols, meanwhile, are receiving many more practice trials than are the majority of the items in the protocols of hierarchy subjects. A simple measure of percent correct on a delayed test or on a speeded test might show an overall advantage for the list subjects, but these subjects would have had more practice on the majority of items. The proper comparisons to make are therefore analyses of breakdowns in the structures that subjects produce in the different conditions. For these qualitative analyses we have adapted a computerized clustering program that is capable of showing, in graphical form, the organization developed by subjects in all four of the conditions. Knowing the idiosyncratic organizations will allow us to describe, categorize, and quantify the types of errors that subjects typically make under speeded recall and under long-term recall situations. This experiment promises to provide the development of new analytical techniques about the effects of organization on learning, speeded testing, and long-term retention.

The qualitative analysis of identification errors under speed stress (R. Pachella and J. E. K. Smith). The reactions of a human operator in man-machine systems become increasingly error-prone with increased emphasis on the speed of responding. In some cases the system can be constructed to attenuate the stressor variable itself, but in many other situations the potential causes of speed stress are beyond the system's control. For example, if the operator's reactions are to signals whose generation is external to the system, then his rate of responding will be paced by the rate of arrival of the signals into the system. In these cases error cannot be totally avoided and equipment must be designed to minimize the sources of error to reduce their impact on the system as a whole. With regard to the potential effects of speed stress, the principles of equipment design have generally emphasized the response components of the system (e.g., the refinement and simplification of manipulanda and controls). At the very best the coding between stimulus and response (S-R compatibility) has been mentioned, but rarely have strictly sensory and perceptual factors been dealt with. The reason for this emphasis has been the implicit assumption on the part of equipment designers that, except at the extreme limits, sensory and perceptual processes take place too quickly to be a major source of error under speed stress conditions. The purpose, then, of this series of studies has been to isolate the sensory and perceptual components of the operator's processing system and to demonstrate the production of errors even under moderate levels of speed stress.

We have intensively investigated perhaps the simplest testing situation imaginable, the direct vocal reading of alphanumeric displays (which presumably maximizes the simplification of response production and S-R compatibility). We have been able to produce systematic matrices of confusion errors resulting from speed stress. These confusion matrices have been analyzed psychometrically, and the conclusion seems to be inescapable that the errors produced are of a sensory and perceptual nature. Two sources of evidence indicate this to be true: First, only the sensory-perceptual parameter of the relevant theoretical model used to fit the confusion matrices is affected by speed stress manipulations. Second, the errors produced by speed stress are of a kind that are similar to (if not identical with) those produced by objectively degrading the stimulus (i.e., reducing stimulus contrast). Thus, an operator performing under speed stress behaves as if he were working with an impoverished stimulus.

<u>Cognitive and response factors and the effect of degraded stimulus input</u> (R. Pachella). As noted above, speed stress affects perceptual processes by effectively degrading the stimulus input with which the operator works. The task used to discover this fact (vocal reading of a display) is an extremely simple one that minimizes the effects of cognitive and response components. The experiments described under this part of the project are intended to investigate how these debilitating perceptual effects interact with cognitive and response factors. Two cognitive factors, stimulus probability and the familiarity of the operator with the display symbols, and one response factor, response difficulty, are being studied. Each of these factors by itself

degrades performance under speed stress: It takes more time to identify an improbable stimulus, an unfamiliar stimulus or a stimulus to which a difficult response must be made (Miller & Pachella, 1973). Further, these factors interact among themselves. For example, the degrading effect of improbability is much greater for unfamiliar stimuli (Miller & Pachella, submitted). However, the key factor for understanding the nature of speed stress, is to see how each of these effects is modified by the presence of a degraded stimulus input.

We have found that degrading the input (the presumed perceptual effect of speed stress) reduces performance by the same amount for all levels of stimulus probability if either the display symbols are relatively unfamiliar (e.g., geometrical forms) or if the response associated with the stimulus is relatively difficult (e.g., a manual response as opposed to a vocal response) (Stanovich & Pachella, submitted). If, on the other hand, relatively familiar display symbols are used (e.g., letters and digits) degrading the stimulus has a much bigger effect, particularly on improbable events. Effectively this means that the enormous advantage shown under normal conditions of using highly familiar display symbols and simple S-R codes will be greatly reduced under speed stress. One cannot count on these factors to protect performance under stressful conditions.

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IV. SUMMARY

This is an annual report of research carried out at the University of Michigan's Human Performance Center under contract F44620-72-C-0019 entitled "Intellectual Performance Under Stress." Experimental results and theoretical progress are reported under the following topics: the role of cognitive structure in the elimination of information overload; manipulation of control processes in memory; retrieval of factual information under speed stress; validation of a test battery of human performance; attention demands and motor performance; learning structured material and subsequent performance under speed stress; the qualitative analysis of errors under speed stress; and cognitive and response factors and the effect of degraded stimulus input. The report lists 15 publications, 2 "in press" articles and 7 articles that have been submitted for publication during the reporting period.

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